

Wind Resource and Wind Shear Characteristics at Elevated Heights

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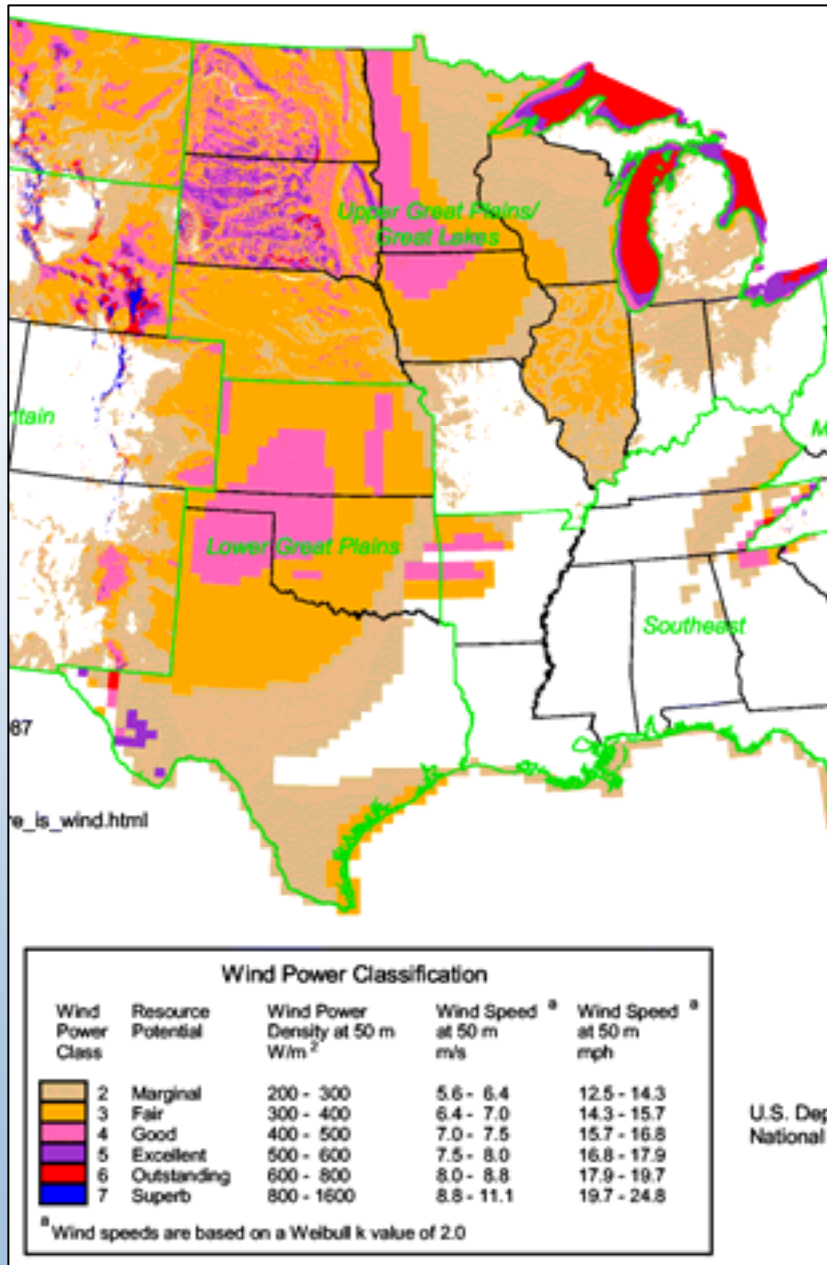
Objectives

- Analyze wind resource and wind shear characteristics at tall tower sites for diverse areas of the Midwest and Central Plains
 - Turbines hub heights are now 70-100 m above ground
 - Wind measurements at 70-100+ m have been rare
- Show case studies and comparisons for some areas of the Midwest (Indiana) and Central Plains (Kansas)
- Present conclusions about wind resource and shear characteristics for prime wind energy development regions

Background

- Tall tower measurements on existing communication towers established during past 5 years supported by:
 - U.S. DOE State Energy Program and Wind Powering America
 - State/university initiatives
 - Other research programs
- NREL obtains time series data from a variety of sources
- Primary areas of investigation to date
 - Central Plains (Windpower 2006 paper by Schwartz and Elliott)
 - 13 tall towers were used in the study, 11 tall towers had highest anemometer at 100-110 m, Kansas had 6 towers
 - Indiana (special study for RPS meeting on Indiana wind resources)
 - High-resolution wind maps by AWS Truewind at 70 m and 100 m
 - 5 tall towers with highest anemometers at 90-100 m

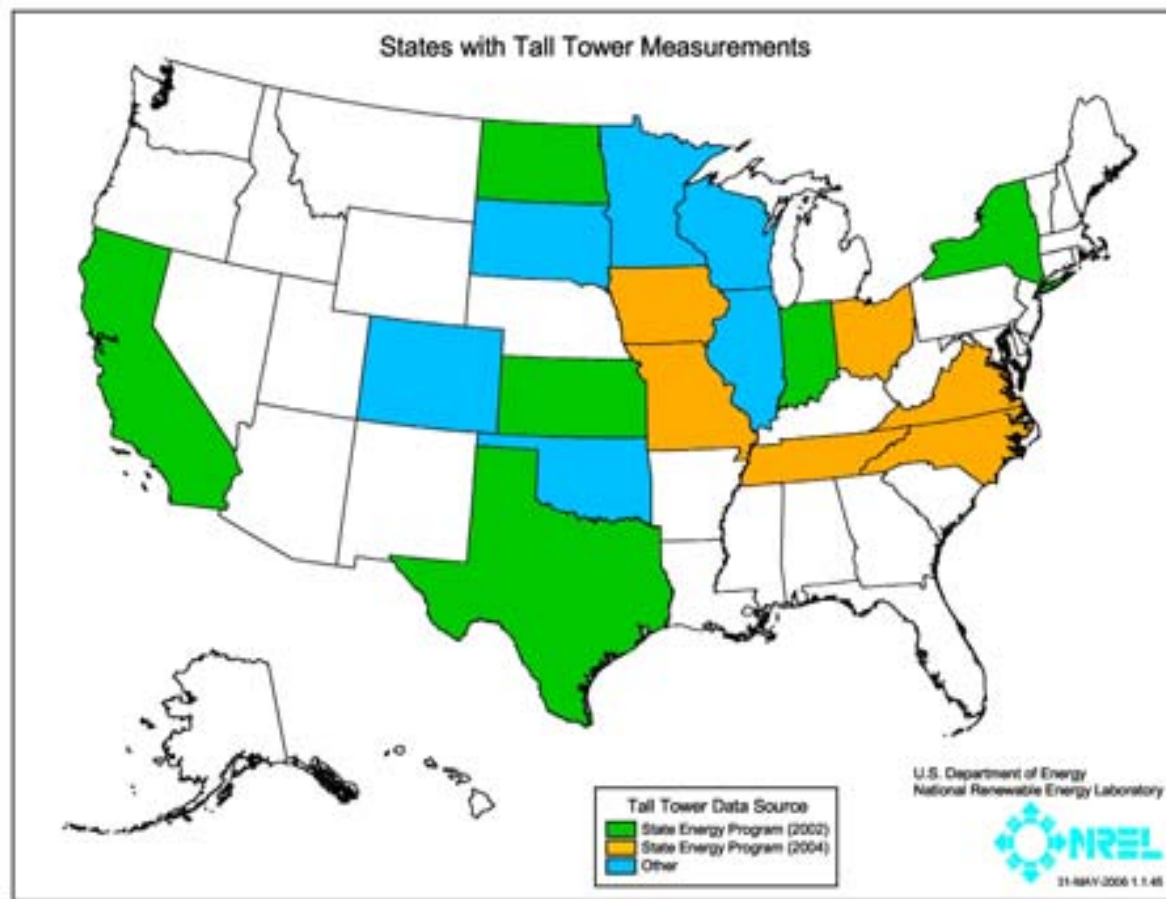
50-m Wind Power Map for Central U.S.



- Considerable uncertainty exists in extrapolating 50-m wind resource to heights of 80-100 m
- Available wind maps for heights of 80-100 m are unvalidated
- Tall-tower wind measurement data needed to examine the wind shear and make more accurate estimates at elevated heights

Current Tall Tower Measurements

- DOE State Energy Program (SEP) 2002 and 2004
 - 12 states
 - 35-40 towers
 - NREL provides technical support
- Other Tall-Tower Data
 - At least 6 states

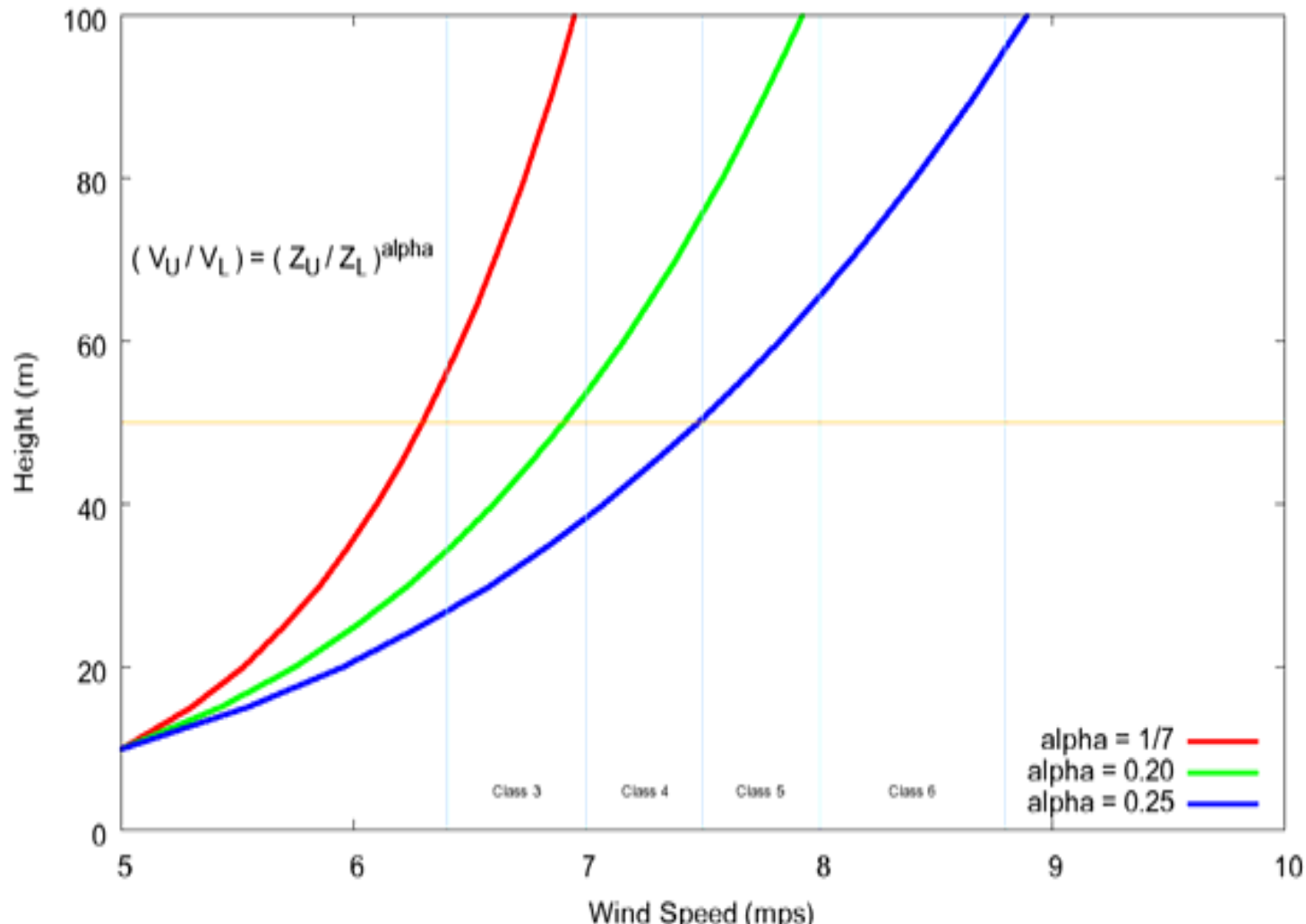




Tall Tower site on the Great Plains.

Communication towers are frequently used for measuring wind energy characteristics at heights up to 100 m or above.

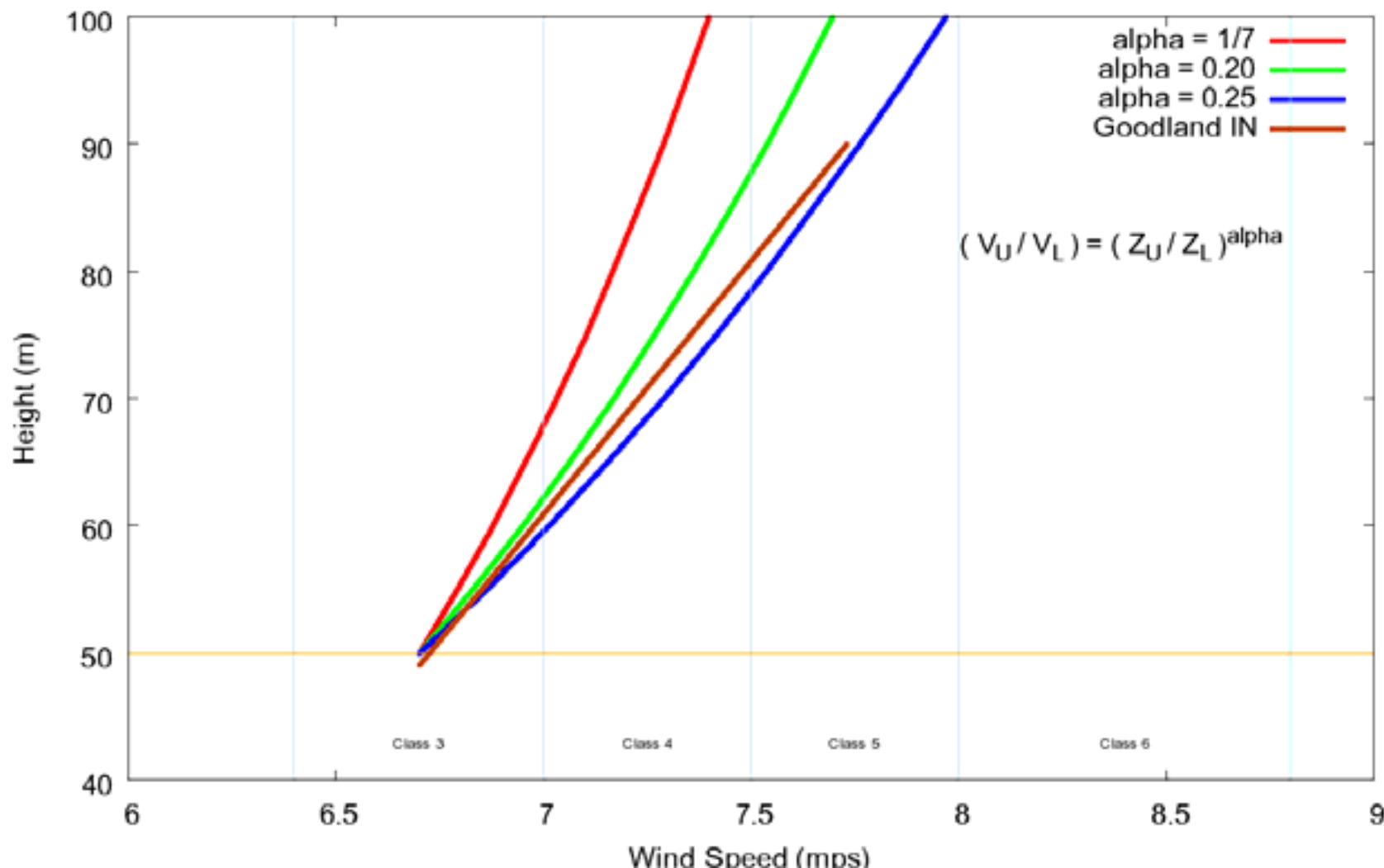
Wind Speed vs. Height for Different Shear Exponents



Annual average shear exponents can vary from 1/7 to 0.25, causing considerable uncertainty in vertical extrapolations of wind resource

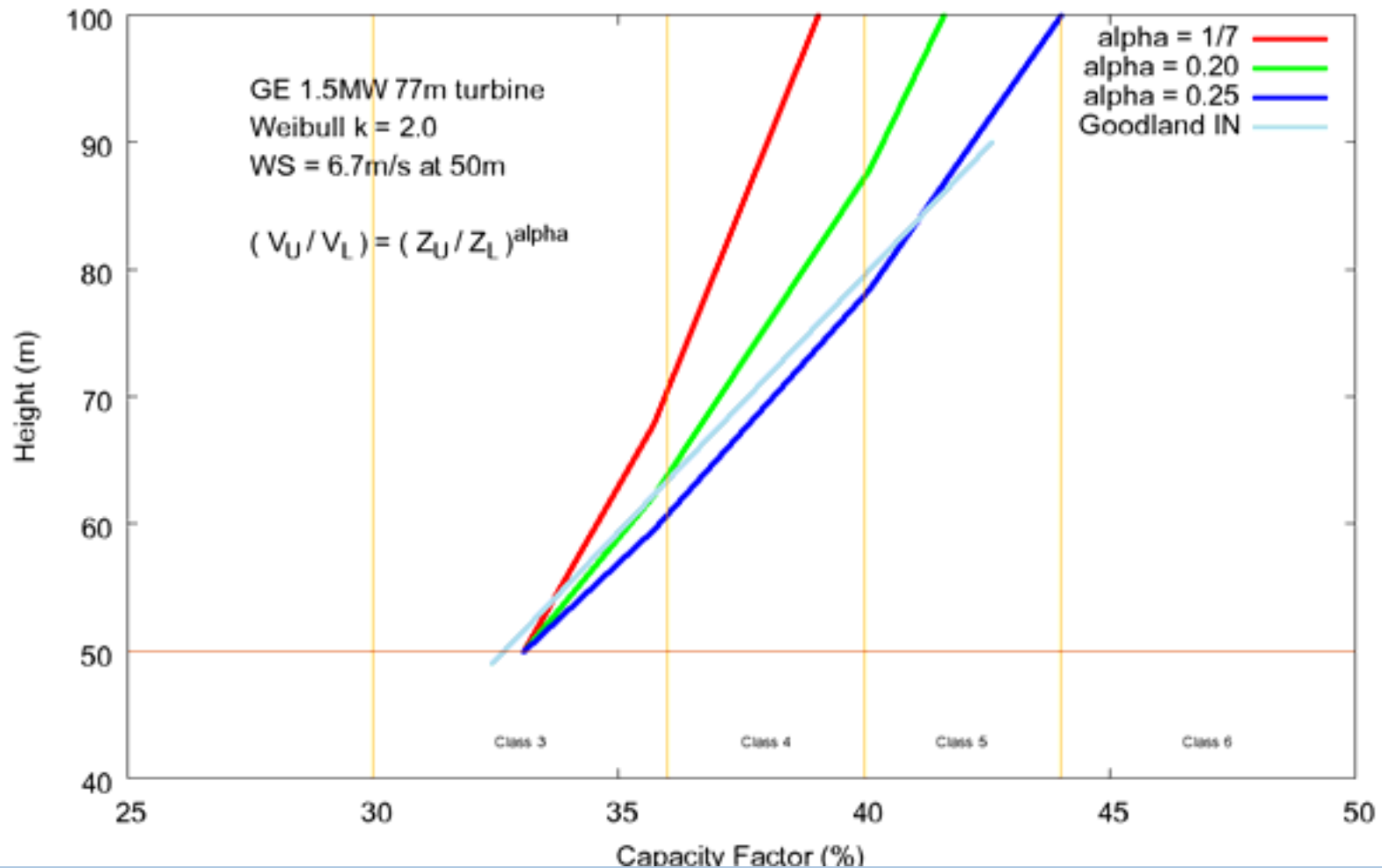


Wind Speed vs. Height for Different Shear Exponents



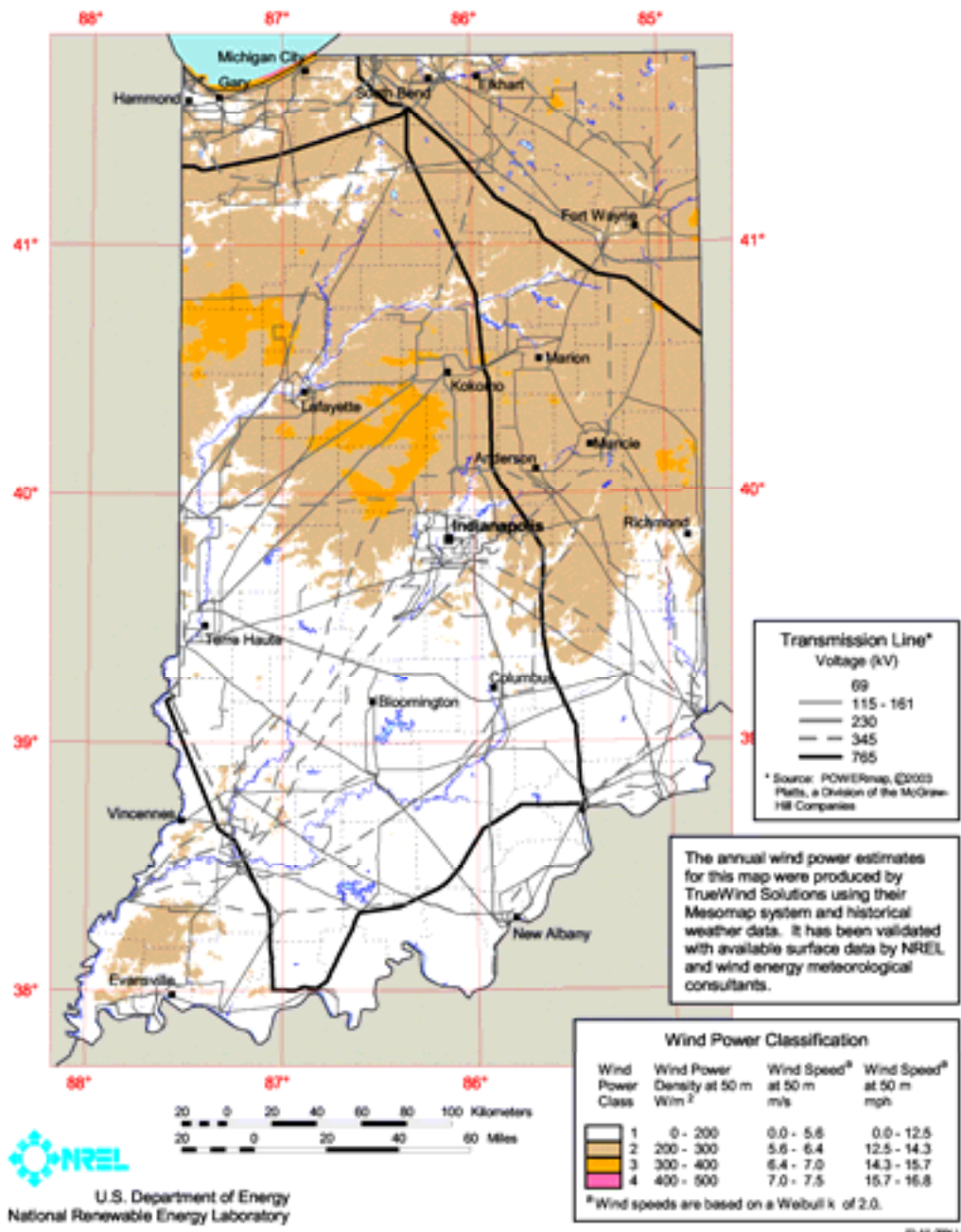
- Even if 50-m wind resource is known, potential variations in shear exponents cause considerable uncertainty in wind resource at heights of 80-100 m
- Measured shear exponent at Goodland is 0.235, with much higher wind resource at 90 m than estimated by 1/7 shear estimate

Capacity Factor vs. Height for Different Shear Exponents



- High wind shear locations can have considerably higher capacity factors at 80-100 m than low shear locations, given similar capacity factors at 50 m
- Goodland's capacity factor of 42.5% at 90 m is considerably higher than would be estimated by using typical shears of 1/7 to 0.2

Indiana - 50 m Wind Power



Indiana Wind Power Map – 50 m Height

- This is the standard wind map product posted on WPA web site
- AWS Truewind used numerical modeling to produce initial wind map estimates
- NREL and consultants used available measurement data to validate the initial estimates
- This final map (produced in 2004) includes the revisions from validation
- Additional map products were produced for heights of 70m and 100m but not validated
- Tall-tower wind measurement program (5 sites) began in 2004



Indiana Tall Tower locations with average wind speeds (m/s) at 99-m height

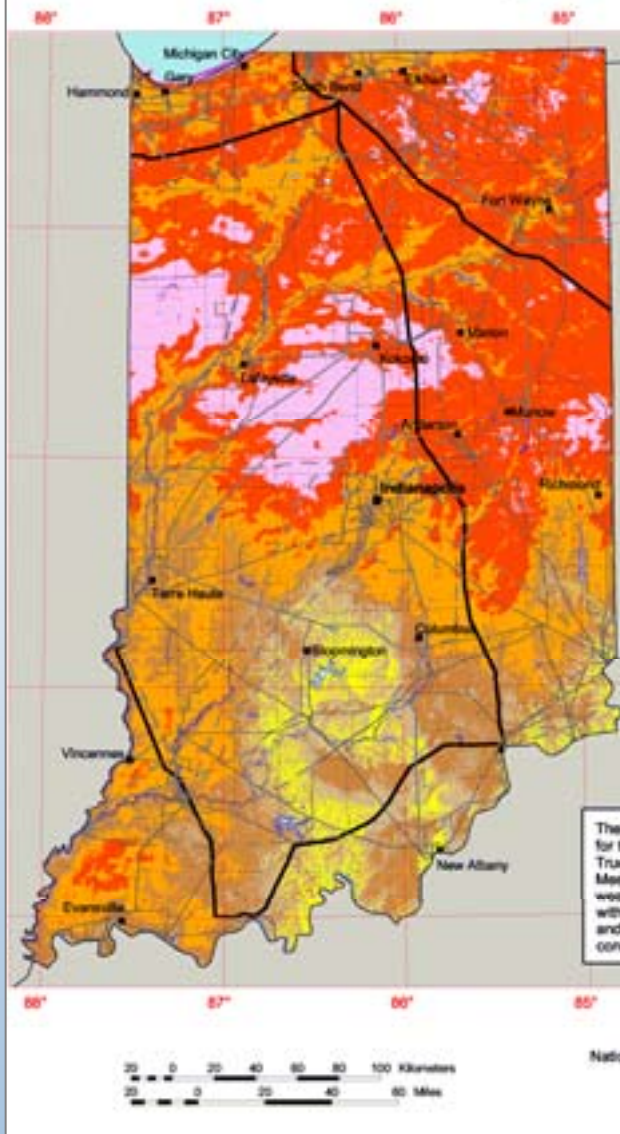
One year of data (mostly 2004). These data became available after wind resource maps were produced.

Goodland's speed based on 90 m measurement

- Capacity factors* at Goodland
- 42% at 90-m height
- 32% at 50-m height

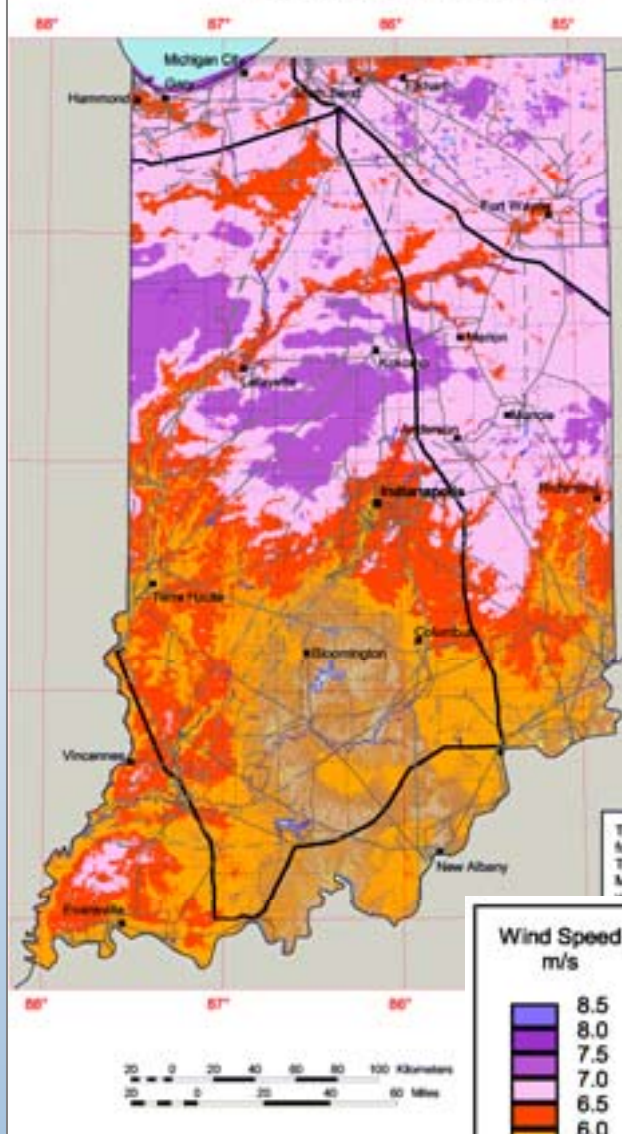
*Capacity factors for GE 1.5 MW turbine with a 77-m rotor diameter

Indiana - 50 m Wind Speed



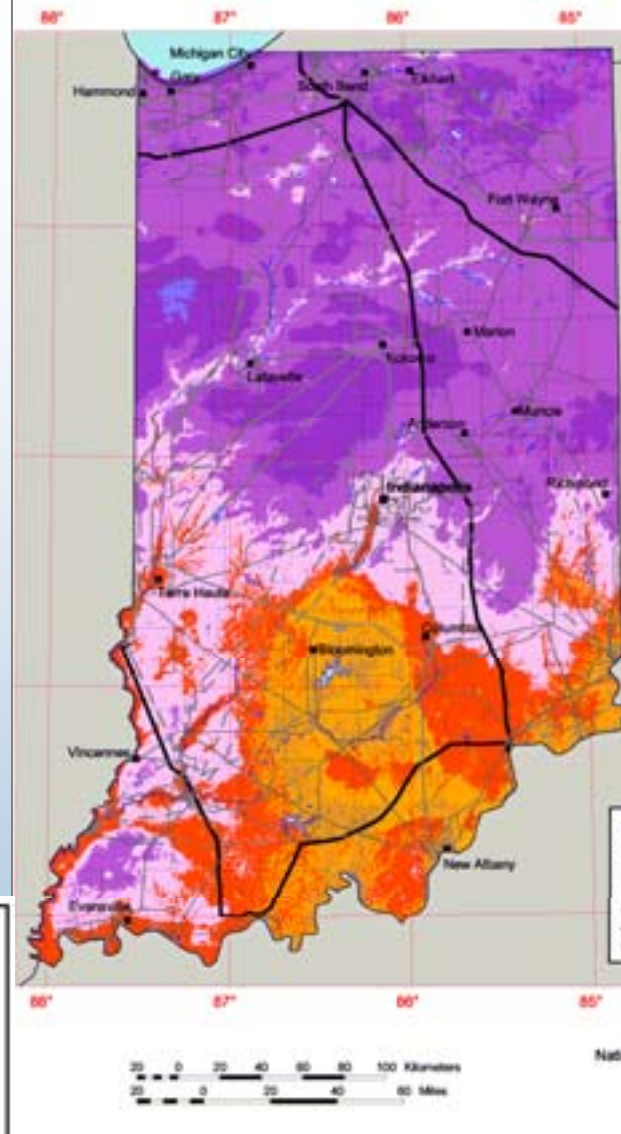
Best areas 6.5-7 m/s
Capacity factors 30-35%

Indiana - 70 m Wind Speed



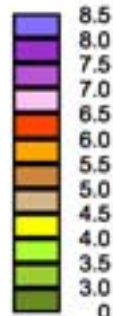
Best areas 7-7.5 m/s
Capacity factors 35-40%

Indiana - 100 m Wind Speed



Best areas 7.5-8.2 m/s
Capacity factors 40-45%

Wind Speed
m/s



Methodology for Estimating Indiana's Wind Electric Potential at 70-m and 100-m Heights

We calculated a range of wind speeds and capacity factors for Indiana wind resources at 70-m and 100-m heights. The wind speed ranges (after 12% power losses) were used to estimate the windy land area and wind potential at map heights of 70m and 100m.

Wind potential was estimated assuming 5 MW of installed wind capacity per square kilometer of available windy land, after environmental and land-use exclusions. Capacity factors were based on the GE 1.5 MW 77-m turbine. If the assumed power losses increase, the wind speeds must also increase to maintain the same capacity factor.

No Power Losses			12% Power Losses	
50-m Class (equivalent)	Speed m/s	Capacity Factor (%)	Speed m/s	50-m Class (equivalent)
Class 3	6.5 – 7.1	30 – 36	7.0 – 7.6	Class 4
Class 4	7.1 – 7.7	36 – 42	7.6 – 8.3	Class 5
Class 5	7.7 – 8.3	42 – 46	Not applicable	

Estimates of Indiana's Wind Electric Potential (Installed Capacity)

Assumes **12% Power Losses**

	70-m Height	100-m Height
Class 4	42 GW	161 GW
Class 5	0 GW	37 GW
Total	42 GW	198 GW

Areas Excluded from Developable Wind Potential

1) Potentially sensitive environmental lands:

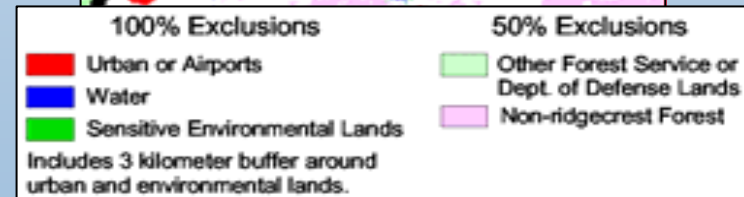
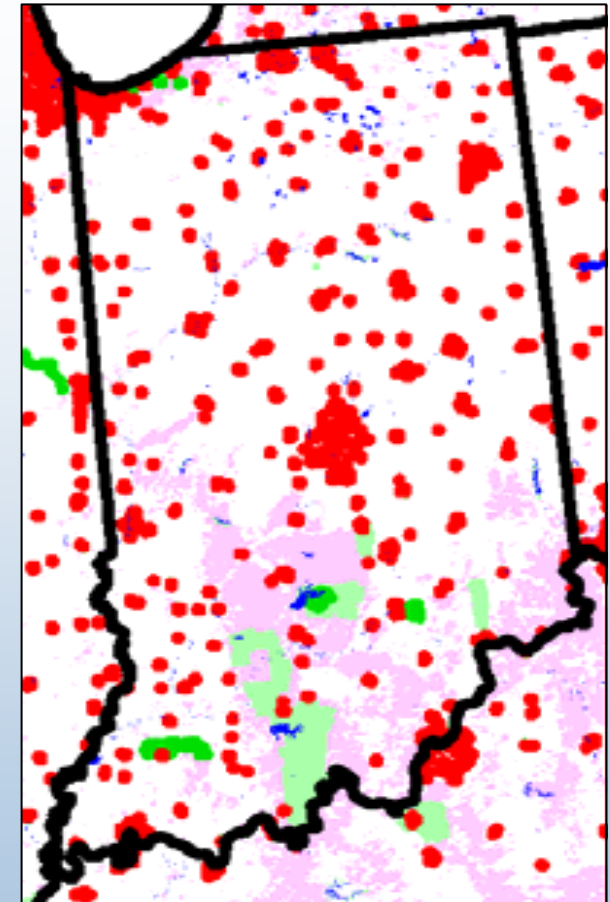
- National Park Service and Fish and Wildlife Service
- Wildlife, wilderness, recreation areas, and other specially designated areas on federal land (predominantly Forest Service and BLM lands)
- Some state and private environmental lands where data was available
- Half of the remaining U.S. Forest Service and Department of Defense lands to represent current dedicated use of land

2) Potentially incompatible land use:

- Urban areas, airports, wetlands and water bodies
- Half of non-ridge crest forested areas

3) Other factors:

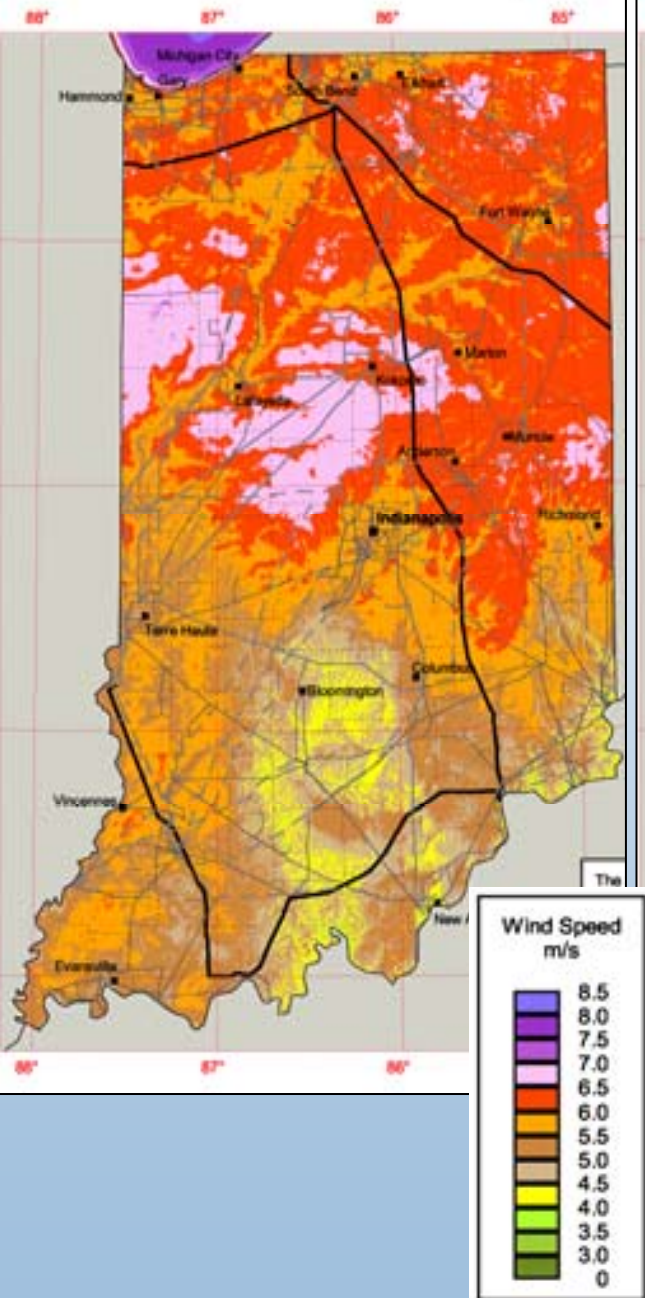
- Slopes greater than 20%
- A 3 kilometer area surrounding environmental and land use excluded areas (except water bodies)
- Small, isolated class 3 and greater resource areas using a minimum density criteria



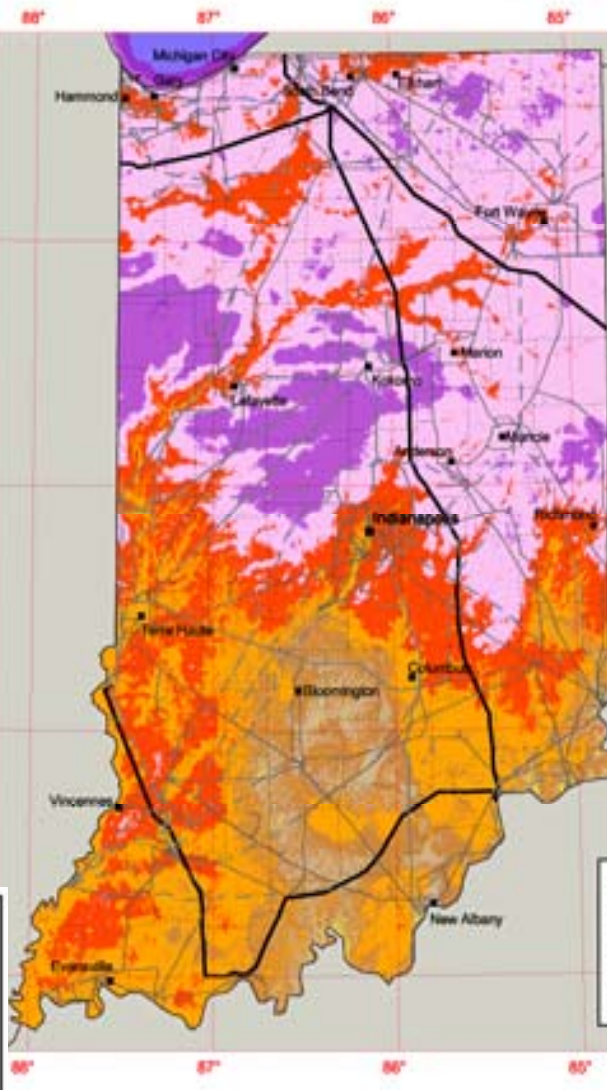
11% of the raw Class 3 and better lands excluded at 70 m (12% loss case)

19% of the raw Class 3 and better lands excluded at 100 m (12% loss case)

Indiana - 50 m Wind Speed



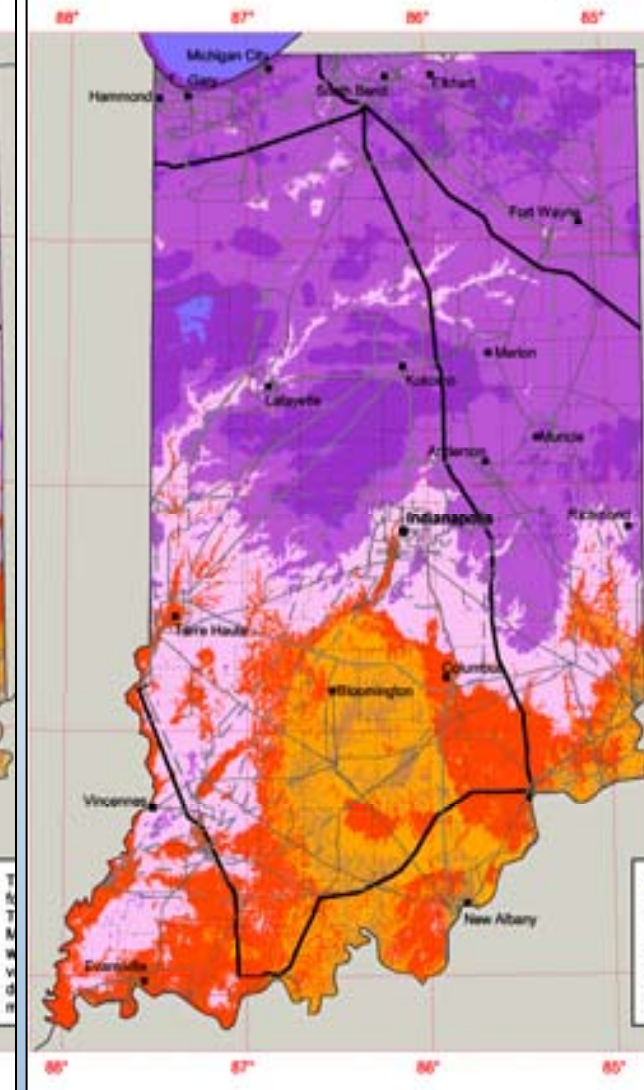
Indiana - 70 m Wind Speed



Wind Potential (Installed Capacity) for
12% Power Loss Scenario
30-36% Capacity Factor: 42 GW

Total: 42 GW

Indiana - 100 m Wind Speed



Wind Potential (Installed Capacity) for
12% Power Loss Scenario
30-36% Capacity Factor: 161 GW
36-41% Capacity Factor: 37 GW
Total: 198 GW

Wind Shear Characteristics Analyzed From Tall Tower Data in Plains and Midwest

- Annual average
- Diurnal variability
- Seasonal variability
- Shear variation by prevailing wind directions
- Investigate wind shear variation by height
- Variations within and among geographic regions



Central Plains Tall Tower Shear Values

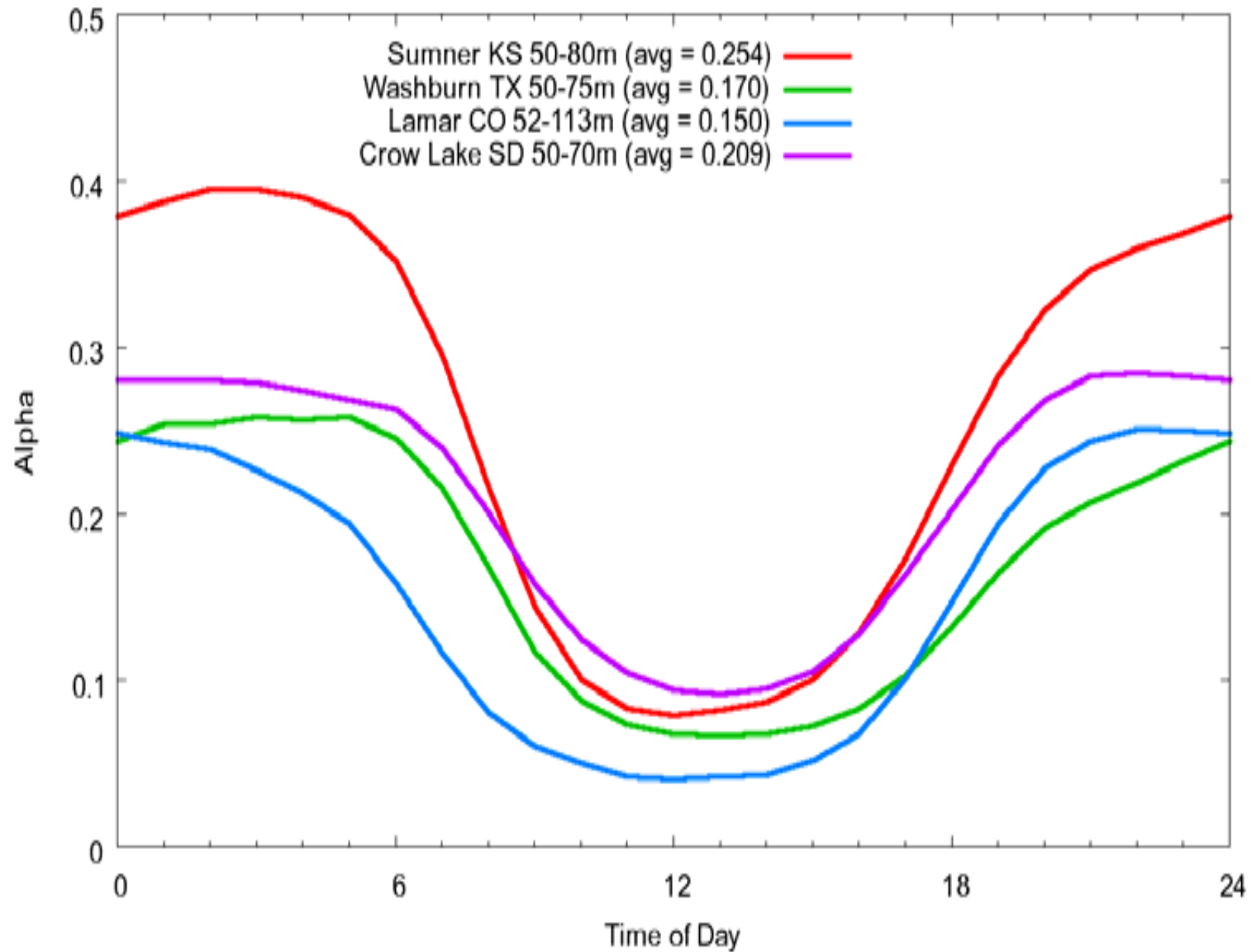


Shear Climate Summary

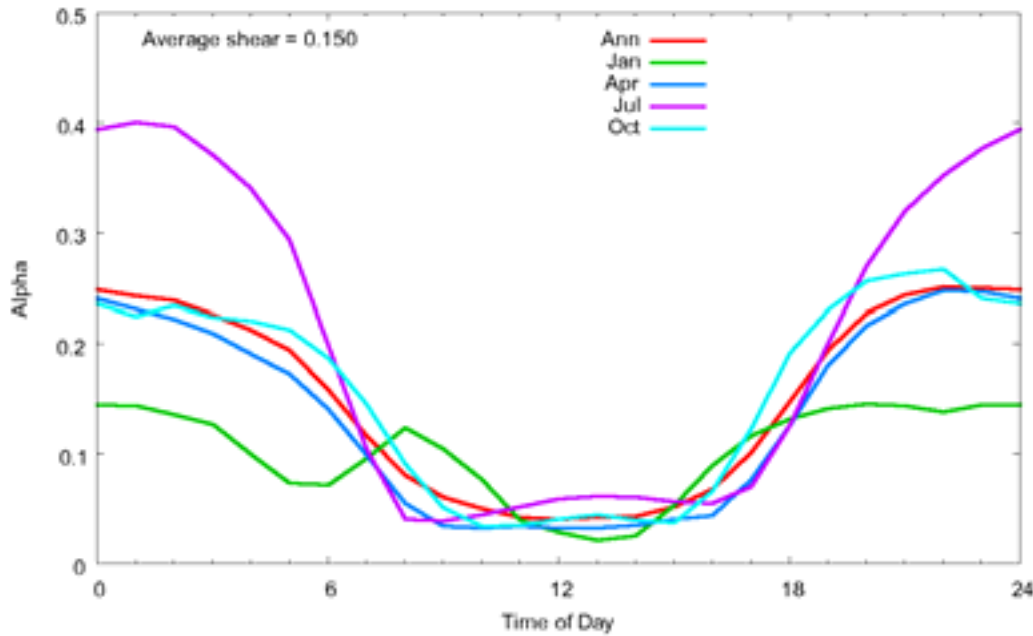
- Annual average shear between 0.15 and 0.25
- Greater variation of annual wind shear between towers within a region than between the southern and northern Plains and the Midwest
- Diurnal shear pattern similar throughout region
 - Daytime shear is 0.05-0.1
 - Nighttime shear between 0.25-0.40
 - Some seasonal variations among towers
- Winds from south had higher shear than winds from north
 - South winds shear 0.2-0.3
 - North winds shear 0.1-0.2



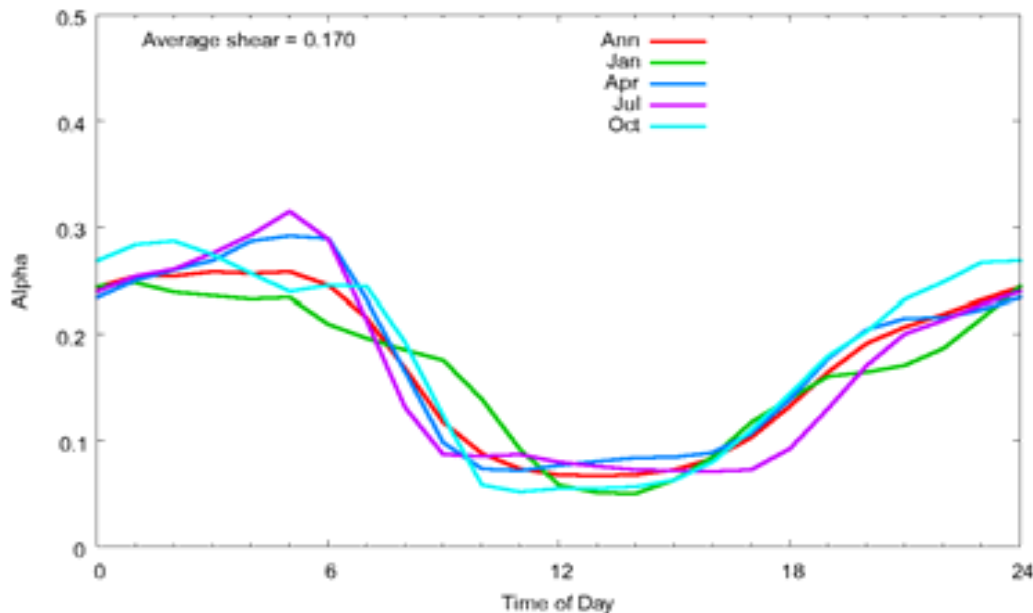
Central Plains Wind Shear by Hour



Lamar CO 52-113m - Seasonal Wind Shear by Hour



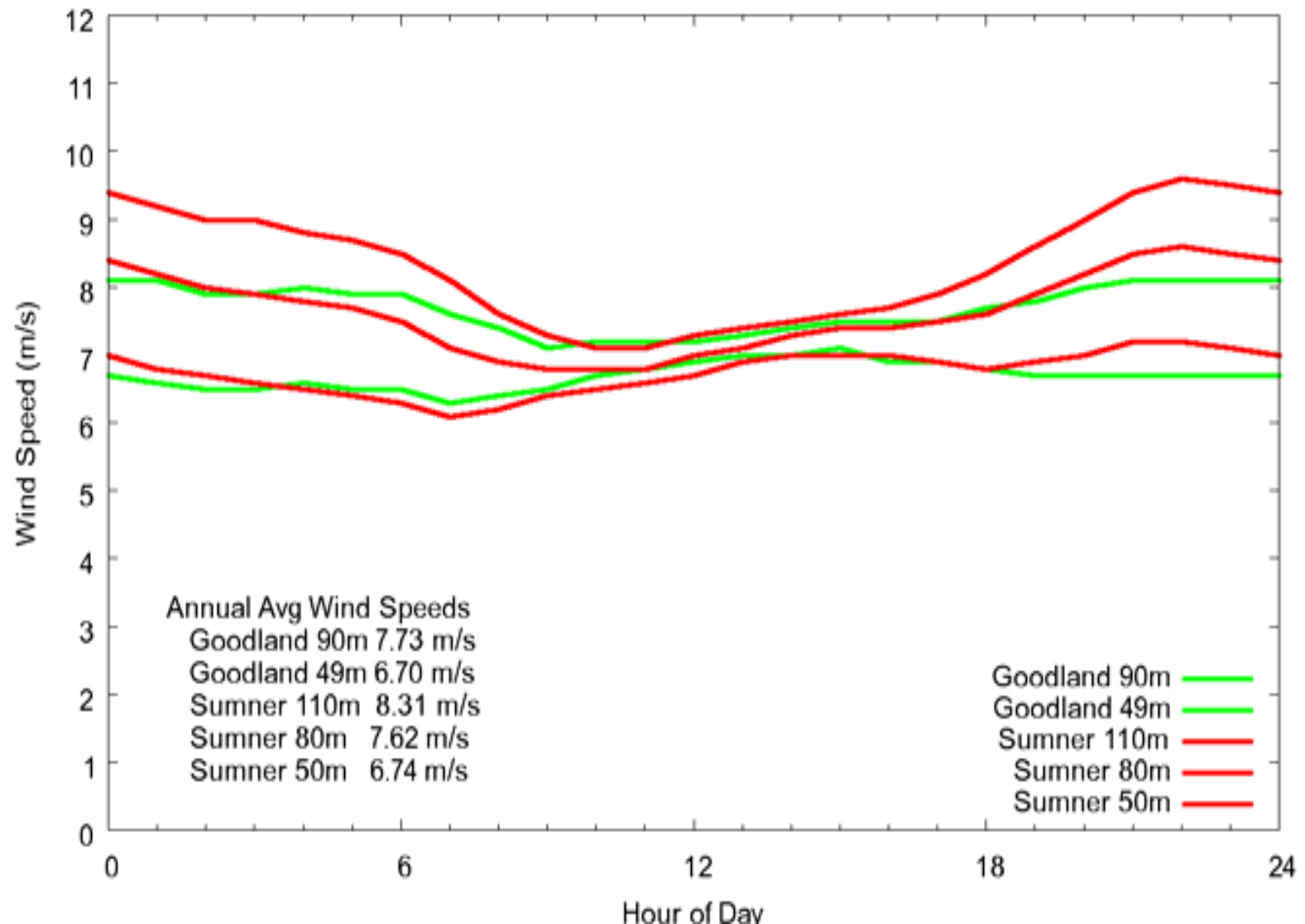
Washburn TX 50-75m - Seasonal Wind Shear by Hour



Seasonal and Diurnal Wind Shear

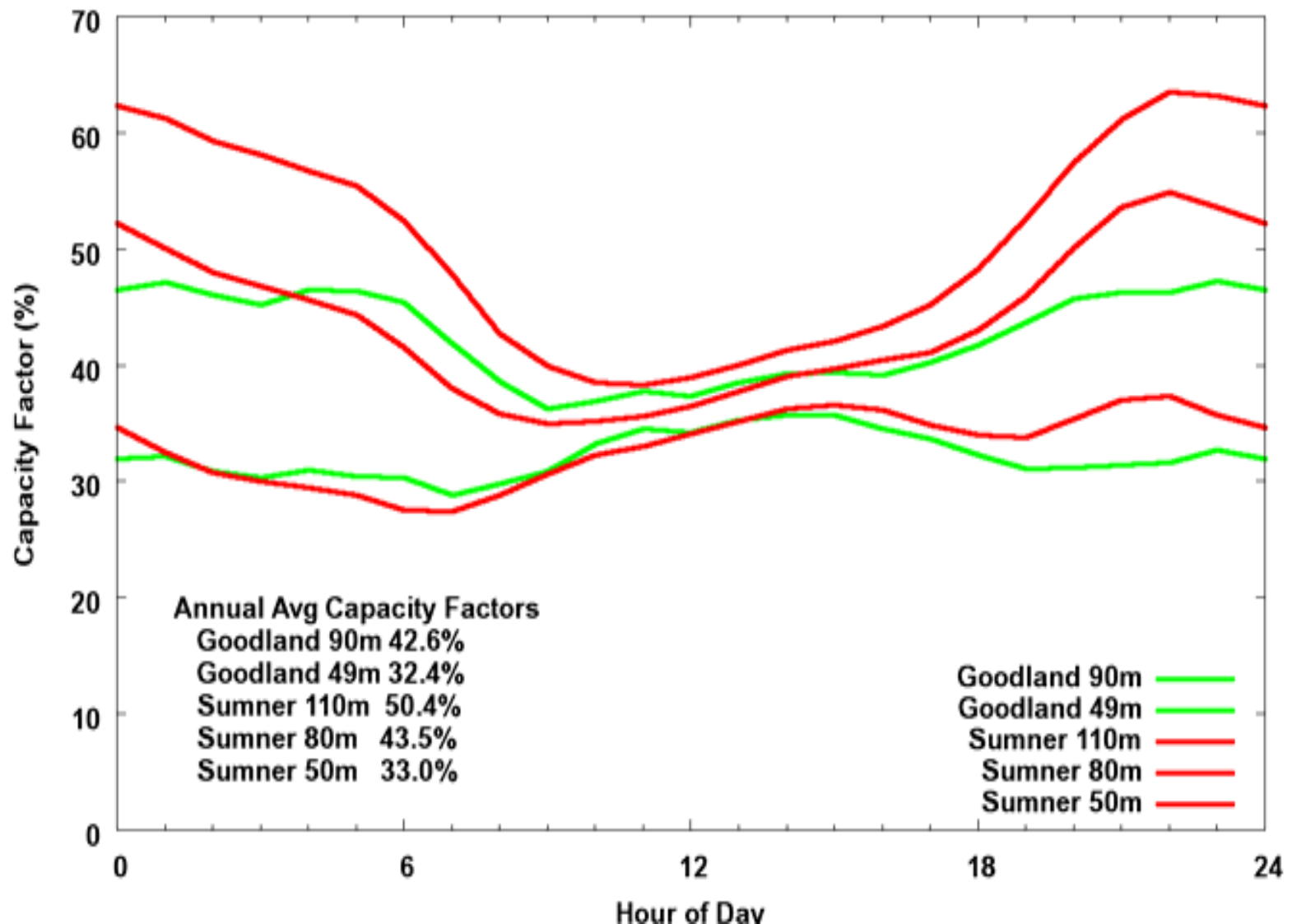
- Lamar CO has much larger nocturnal shears in summer than in winter
- Washburn TX has similar nocturnal shears across the seasons

Wind Speed by Hour - Goodland IN and Sumner KS



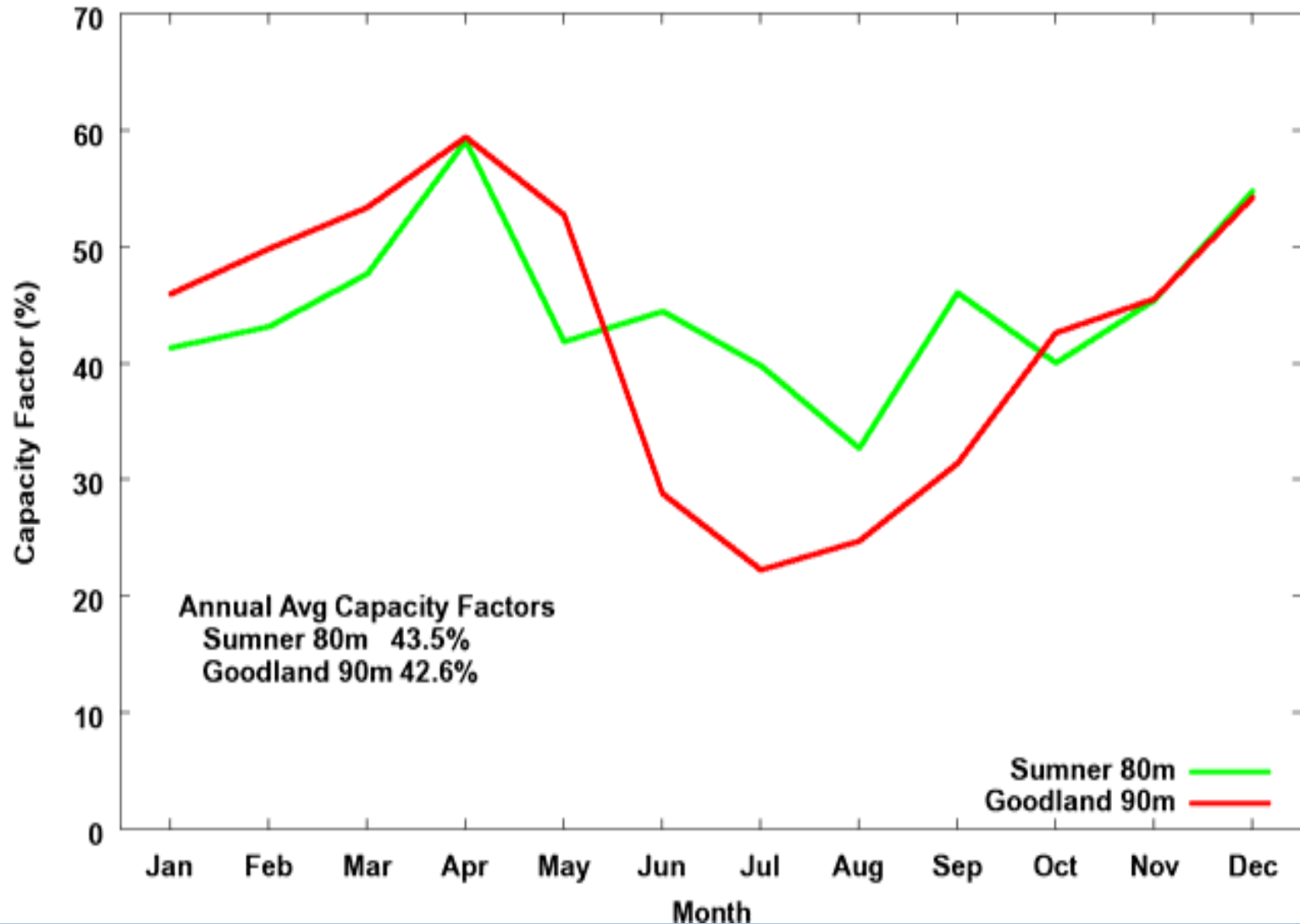
Goodland IN and Sumner KS have similar wind resource and wind shear

Capacity Factor by Hour - Sumner KS and Goodland IN



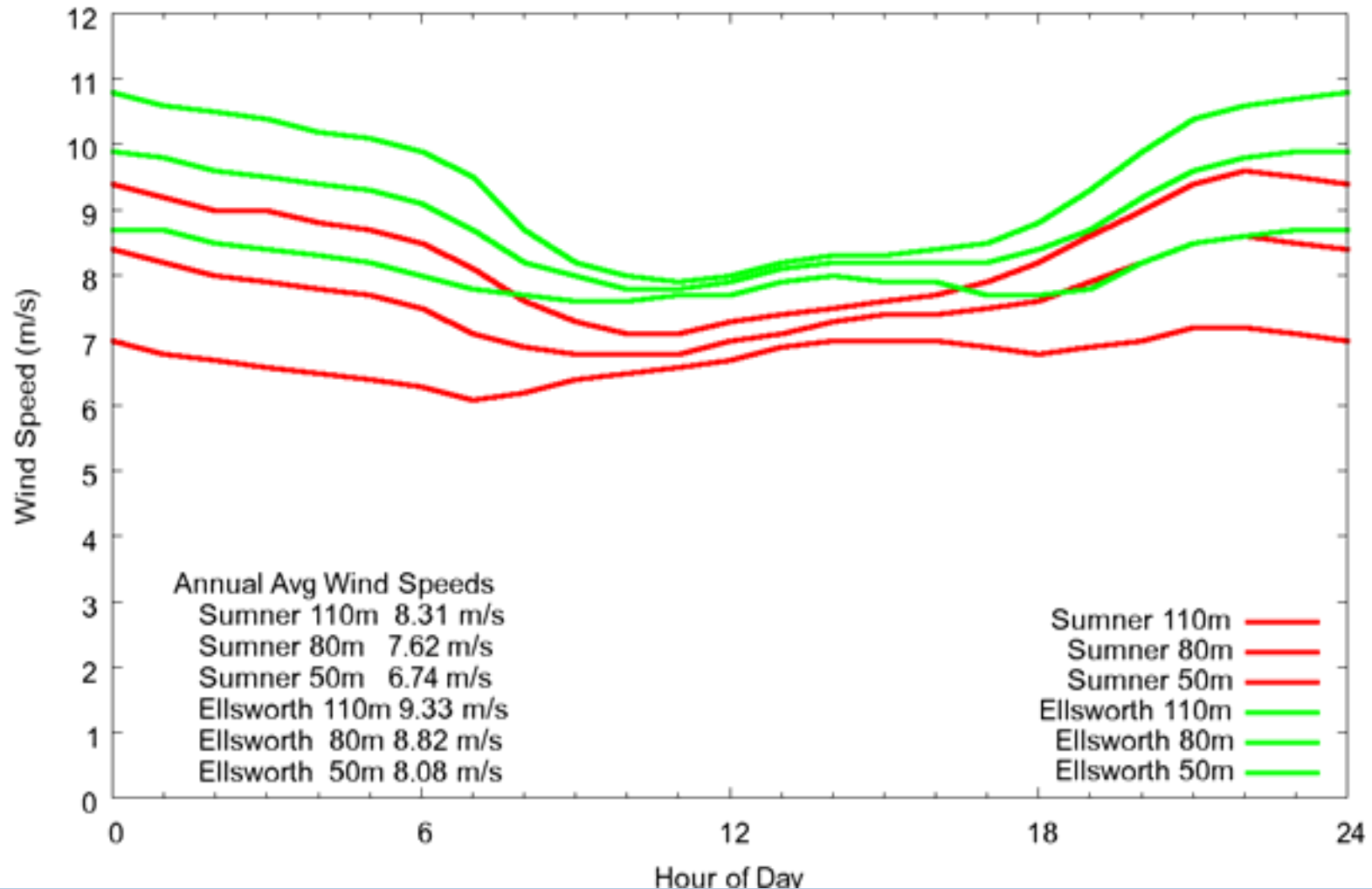
Goodland IN and Sumner KS have similar capacity factors and both locations have large increases in capacity factors between 50 m and 80-90 m heights

Capacity Factor by Month - Sumner KS and Goodland IN



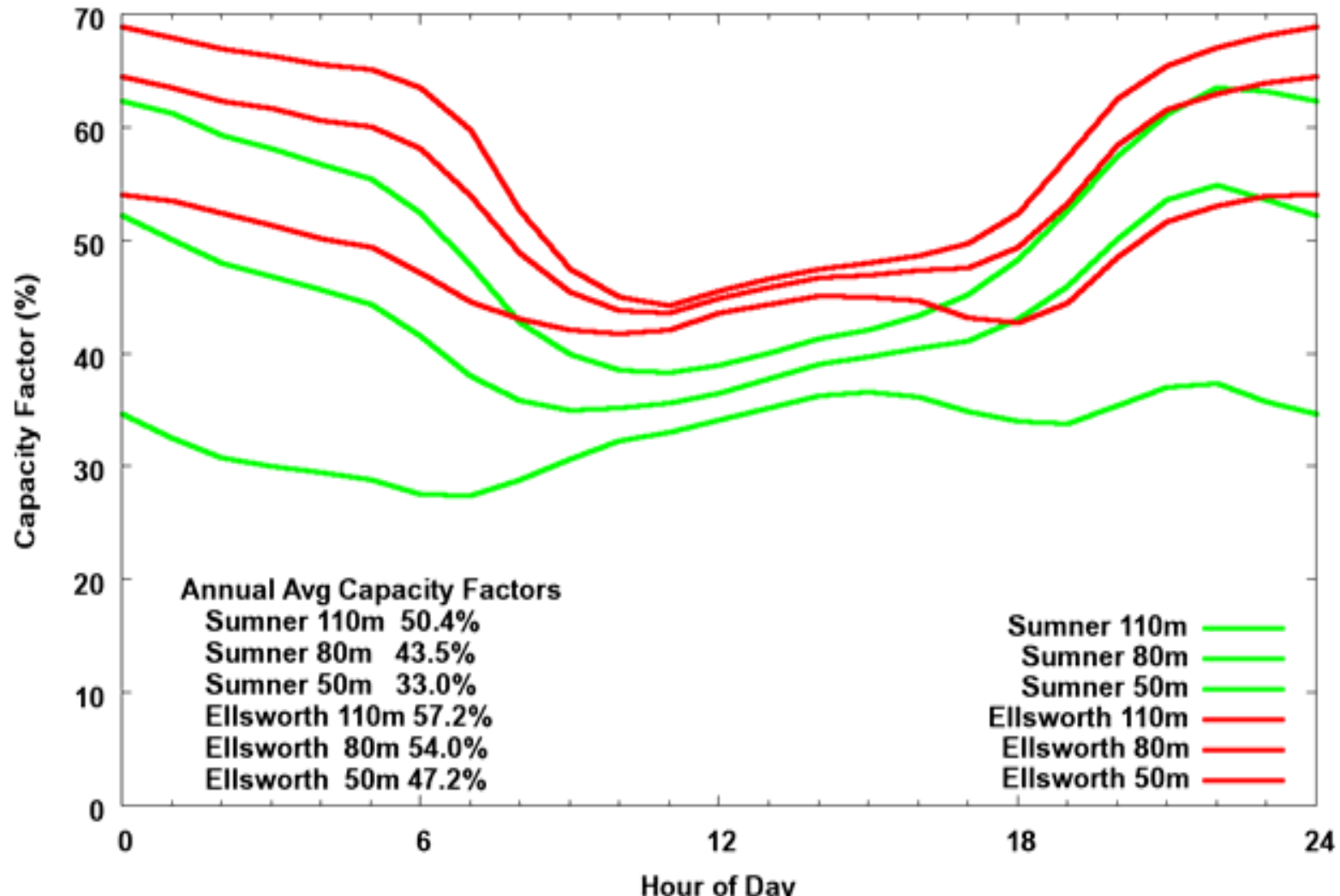
Goodland IN has larger seasonal variations than Sumner KS in capacity factors at 80-90 m

Wind Speed by Hour - Sumner KS and Ellsworth KS



- Comparison of wind resources at two locations in central Kansas
- At 50m, Sumner is Class 3 and Ellsworth is Class 4-5
- Wind shear is greater at Sumner than Ellsworth, and speed differences decrease with increased height

Capacity Factor by Hour - Sumner KS and Ellsworth KS



- Comparison of capacity factors at two locations in central Kansas
- Capacity factors increase more rapidly with height at Sumner than at Ellsworth
- Difference in capacity factors halved at 80-110 m compared to 50 m

Conclusions

- Tall-tower data from Midwest and Plains regions indicate many locations can have high annual average wind shear (0.2-0.25) at heights between 50-100 m
 - At these locations, Class 3 sites at 50 m can have Class 4-5 equivalent wind resource at 80-100 m heights and gross capacity factors exceeding 40%
- Variations of annual wind shear within a region can be greater than variations among different regions
 - Within a region, less energetic wind resource locations at 50 m tend to have greater wind shear than more energetic locations
- Additional tall-tower data are needed to characterize the wind resource and wind shear in wind energy development regions